

- ATP declines at the discharge, relative to intake values, were also observed in July and November 1975 in another study (Appendix B.2). However, these declines were not consistent with entrainment-related changes in chlorophyll a and carbon-14 productivity. These latter results suggest that ATP measurement is not a satisfactory method for defining entrainment effects on phytoplankton. It is possible that ATP measurements are sensitive to water being withdrawn from the deeper layers of the Bay. In these waters, the physiological state of plant cells and heterotrophic (bacterial) activity may be the primary influence on ATP determinations.

III.4.3. Entrainment Effects on Productivity

- Declines in ^{14}C productivity values were consistent with entrainment-related declines in chlorophyll a concentrations (Appendix B.2). These changes occurred in the fall, indicating that they might have been caused by the mechanical disruption of microflagellate cells.
- Reductions of approximately 30% in ^{14}C productivity were observed between the intake and discharge (Appendix B.3) for experiments during spring, summer, and fall in 1978. Productivity measurements using net oxygen production also showed declines between intake and discharge on the average (Ref. 156); however, these determinations were highly variable with respect to ^{14}C values.
- In 1978, entrainment related declines in productivity were observed, but in 1979, productivity enhancement was observed (Appendix B.11).

III.4.4. Summary on Entrainment Effects

- Although productivity declined at the discharge during spring, summer, and fall (Appendix B.3), the largest and most consistent entrainment effects occur during the fall. These entrainment effects are probably related to cellular disruption of a sensitive and highly productive portion of the phytoplankton community--the microflagellates and nannoplankton. Autoradiographical studies (Appendix B.3) imply that entrainment effects may be species-specific. It is unlikely that thermal stress is responsible for the observed effects.

III.4.5. Nearfield Changes in Biomass

- Although qualitative comparative analyses of chlorophyll a over the ERDA station array during preoperational and operational

periods show some changes (Appendix B.4), rigorous statistical analyses of surface distributions (Appendix B.5) reveal no power-plant-related effects. Associated particulate values (carbon and nitrogen) show some changes, but these are believed to be due to outliers in the data set.

- No significant differences were observed between plume- and reference-station chlorophyll a values (Appendix B.7).
- No consistent statistical differences were observed among plume and nearfield stations in total phytoplankton cell densities or in composition (Appendix B.9). There was some evidence for defining a weak natural estuarine gradient in total cell counts. Results of taxonomic analyses from operational periods agree with those from the preoperational period (Appendices B.10 and B.8).

III.4.6. Nearfield Changes in Productivity and Assimilation Ratio

- Surface (^{14}C) primary production shows no power-plant-related effects (Appendix B.5). The reportedly lower productivity during the operational period (Appendix B.4) is due to annual variation over the entire segment of the Bay around the site.
- Although plume values of net and gross photosynthesis (determined by oxygen production) showed depressions relative to other stations (Appendix B.7), these differences were not statistically significant. Primary production measurements by oxygen evolution are believed to be highly influenced by heterotrophic activity (Appendix B.3), and this phenomenon might be related to the increased respiration values observed in the plume (Appendix B.7). The fact that lower-layer waters discharged by the plume could contain stressed, dead, and physiologically inactive organisms, as well as bacteria, may also influence respiration measurements, which in turn, modify apparent productivity as measured using O_2 . No significant differences were found for assimilation ratios.

III.4.7. Summary on Nearfield Effects

- In spite of the variability in phytoplankton community variables and the large uncertainties in determinations of productivity, two findings -- that measured plant entrainment effects are small and that dilution of the plume is so rapid -- lead to the conclusion that plant-related changes in properties of the phytoplankton community in the nearfield are small and are confined to an area less than that of the average 2°C excess temperature isotherm (Appendix B.5).
- Since no significant nearfield changes in nutrient distributions resulted from cooling system operation, no enhancement or decline

of the phytoplankton community can be expected from the response of productivity and biomass to environmental change.

III.5. - SIGNIFICANCE OF FINDINGS

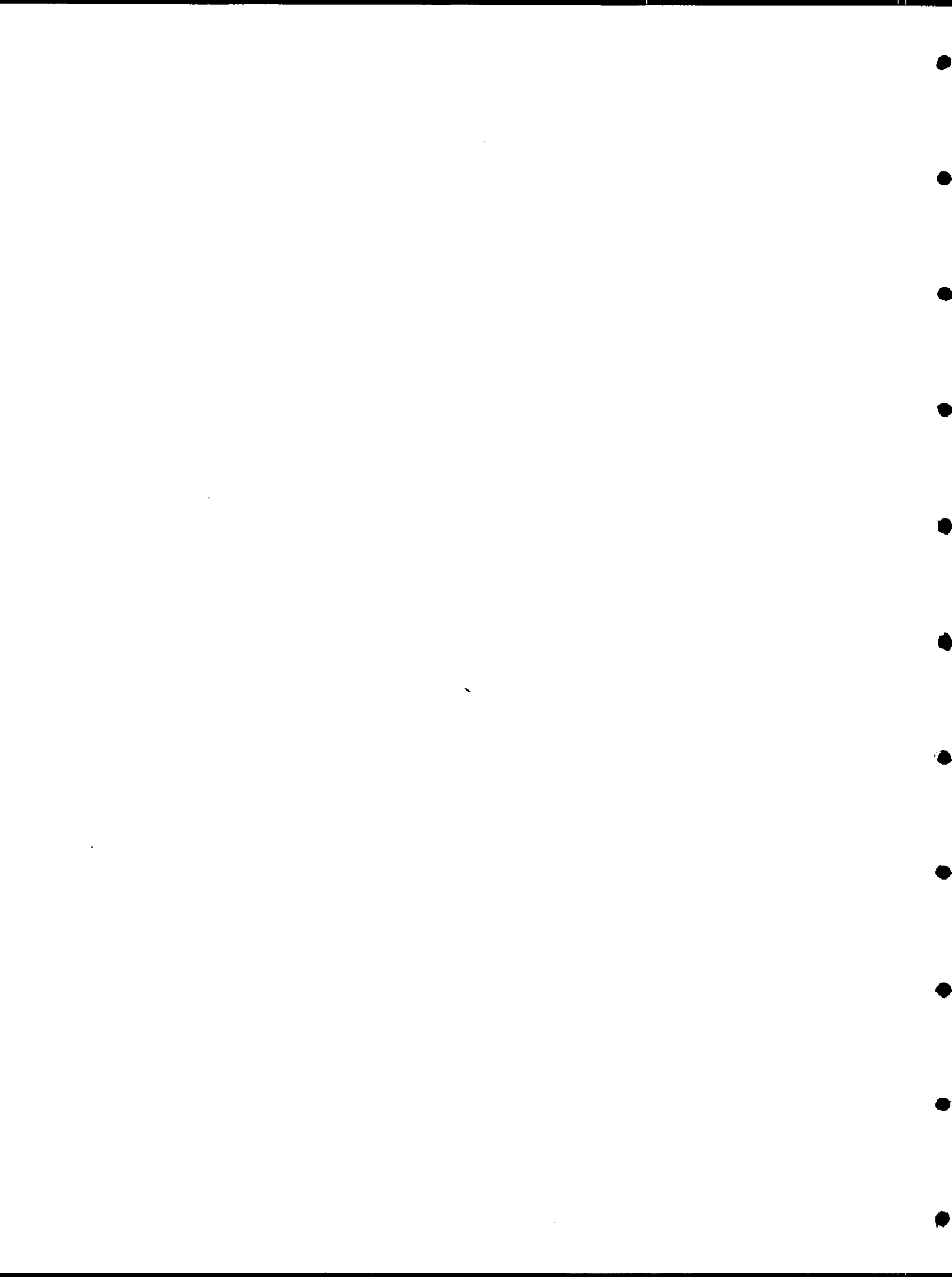
- The operation of the Calvert Cliffs Nuclear Power Plant causes neither substantial enhancement nor decline in Bay primary productivity.
- The observed effects of power plant operations on phytoplankton community variables are consistent in magnitude with the small, observed entrainment effects and with the physical scales of perturbation discussed in Chapter II.
- The propagation of the small power-plant-induced effects on phytoplankton to higher trophic levels would be undetectable.

Table III-1. Modes and possible consequences of interactions between phytoplankton and a power plant.

Direct Interaction	Types of Stress (or Effects)	Possible Consequences to Organism	Possible Consequences to Population
Vertical redistribution (due to withdrawal of deep water and its discharge at surface)	Light shock (i.e., exposure of dark-adapted cells to excessive illumination)	Decreased productivity	Decline in population growth
Plant entrainment	Thermal Mechanical	Mortality Decreased productivity Enhancement of productivity	Decline in population growth Alteration of community composition due to differential mortality or enhancement of different species
Plume entrainment	Thermal	Decreased productivity Increased productivity	Change in population size (increase or decrease, depending on conditions) Alteration of community composition due to differential mortality or enhancement of different species

Table III-2. Descriptions of studies conducted at Calvert Cliffs relating to plant impact on phytoplankton.

STUDY	RELEVANT SUMMARY APPENDICES	PARAMETERS MEASURED	SAMPLING METHOD	STATION LOCATIONS	SAMPLING FREQUENCY	PERIOD OF DATA COLLECTION	INFORMATION OBTAINED	REFERENCES AND SOURCES (REF. NOS.)
ENTRAINMENT								
1 Phytoplankton entrainment (BG&E)	B.1	ATP, taxonomy	Pumped samples	Intake and discharge	At least monthly, June - September	1975 - present	Entrainment effects on phytoplankton	1,2,40-42, 167
2 Phytoplankton entrainment (CBL for PPSP)	B.2	Productivity (^{14}C), chlorophyll <u>a</u> ; ATP	Pumped samples	Intake and discharge	Quarterly	1975	Entrainment effects on phytoplankton	60
3 Phytoplankton entrainment (CBL for PPSP)	B.3	Productivity (^{14}C and O_2); chlorophyll <u>a</u> autoradiography; fluorescence	Pumped samples	Intake and discharge	Spring, summer, fall	1978-1979	Entrainment effects on phytoplankton	61, 156
4 Phytoplankton entrainment (ANSP for BG&E)	B.11	Number of phytoplankters by taxonomic group, ^{14}C , productivity (O_2 and ^{14}C), and chlorophyll <u>a</u> .	Pumped samples	Intake, discharge tunnel, and plume	Monthly in summer	1978 and 1979	Entrainment effects on phytoplankton	168
NEAR FIELD STUDIES								
5 Primary productivity (CBL for ERDA and PPSP)	B.4 B.5	^{14}C fixation under constant conditions, chlorophyll <u>a</u>	Pumped samples at surface and near bottom	Plant site and reference stations	Monthly	1971-1978	Phytoplankton potential productivity	50, 115-117, 140, 146
6 Phytoplankton productivity and biomass survey (ANSP for BG&E)	B.6 B.7	Primary productivity (O_2), chlorophyll <u>a</u>	Whole water samples incubated on deck or <u>in situ</u>	Plant site and reference stations	Monthly	1971 present	Rate of primary production; biomass density	1,2,30, 38-42, 167
7 Phytoplankton survey (ANSP for BG&E)	B.8 B.9	Numbers of phytoplankters by taxonomic group	Samples at surface and 30-ft depth	Plant site and reference stations	Monthly	June 1969 to May 1970 and 1974 to present	Species distribution and abundance	1,2,26, 38-42, 167
8 Catherwood diatometer study (ANSP for BG&E)	B.10	Abundance, growth, and species diversity of diatoms	Catherwood diatometers anchored in floating position at each station	Plant site and reference stations	Biweekly	1971-1973	Diatom species abundance and diversity	22, 23



IV. ZOOPLANKTON

IV.1. -- INTRODUCTION

Zooplankters are animals whose distributions are governed largely by water movements rather than by their own swimming ability. They are primary grazers on phytoplankton and are also an important food source for organisms in higher trophic levels. They thus form an important link in the food web. Environmental perturbations, either natural or man-induced, that modify zooplankton abundances or community structure can result in significant alterations of aquatic food pathways. Because of their ecological importance and limited ability to avoid environmental changes, several studies have been carried out to assess the impact of the Calvert Cliffs plant on local zooplankton populations.

The zooplankton community in the Calvert Cliffs area is typical of that found in other temperate Atlantic Coast estuaries (Refs. 127-132) and is similar to those described for other parts of the Chesapeake Bay (Refs. 40, 133-135). Highest abundances tend to occur in spring (March-April) and late summer (August-September). The winter-spring community is dominated by rotifers, tintinnids, and the calanoid copepods Eurytemora affinis and Acartia clausi. Acartia tonsa is present throughout the year and dominates the late summer zooplankton population. The most common cyclopoid copepods are of the genus Oithona and are present primarily in the fall. Harpacticoid copepods are represented by species of the Ectinosomidae and Laophontidae families and appear in spring months (Ref. 99). Barnacle nauplii have been shown to peak in late spring and again, to a lesser extent, in fall (Refs. 42, 99). Organisms such as polychaete larvae, bivalve larvae, and rotifers are present in considerable numbers at specific times throughout the year.

IV.2. - MODES OF ZOOPLANKTON-POWER PLANT INTERACTION AND THEIR SIGNIFICANCE

Zooplankton interact with a power plant either by being entrained through the plant cooling system or by being entrained into the discharge plume (Table IV-1). In some studies, the magnitude of zooplankton mortality associated with entrainment through the plant has been shown to be directly proportional to duration of exposure to elevated temperatures (Ref. 136). In the case of Calvert Cliffs, the rapid passage of organisms through the cooling system (approximately four minutes) and the moderate increase in the temperature of the water (5.5°C), limit the thermal dose experienced by entrained organisms to 22°C degree-minutes. This dose can be compared to that for the Morgantown steam electric station, which produces a thermal dose of 260°F degree-minutes for a similar temperature rise (Ref. 137). Thus, thermal stresses imposed by the Calvert Cliffs plant should be relatively low.

Entrained organisms may also experience mechanical damage associated with abrasion, velocity shear, and pressure changes. This mechanical damage can result in mortality or in morphological or physiological impairment. If biocides were used in the cooling system, entrained organisms would experience chemical stress; however, no biocides are used at Calvert Cliffs.

In addition to direct mortality, entrainment may cause deleterious sublethal effects on zooplankton, which include: organisms becoming comatose and "sinking" after experiencing heat shock and disorientation; eggs being stripped from female copepods, resulting in lower reproductive potential; and morphological damage, which increases vulnerability to predation. Since these organisms lack the mobility required to avoid the plant, they may be entrained more than once, possibly compounding these sublethal effects.

Thermal rises experienced by organisms entrained in the discharge plume, a short distance from the discharge conduit at Calvert Cliffs, are on the order of 1° to 2°C. This relatively small temperature rise combined with the further rapid dispersion of heated water causes only limited thermal stress to plume entrained organisms -- less stress than that experienced by organisms actually entrained through the plant.

IV.3. - MONITORING STUDIES

Descriptions of studies conducted at Calvert Cliffs to determine plant impacts on zooplankton are outlined in Table IV-2. Detailed descriptions of methods and more comprehensive discussion of findings can be found in relevant summary appendices (the C appendices) or original data sources. Studies conducted for zooplankton can be categorized as either entrainment or near-field studies.

Entrainment studies examine differences in zooplankton densities and differences in live-dead ratios of organisms between the intake and discharge sites. Declines in the densities of individual groups between the two sites would indicate either mechanical destruction of the zooplankters or nonrepresentative (inaccurate) sampling, while a decrease in live-dead ratios from intake to discharge would indicate mortality attributable to either thermal or mechanical stresses. Study 1 (Table IV-2) was concerned with density and live-dead differences between intake and discharge locations over extended (sampling monthly) and shorter (sampling half-hourly) periods. Study 2 was designed to determine whether decreases in sampled zooplankton densities from the intake to the discharge are due to errors in sampling design or are a result of mechanical or thermal effects to entrained zooplankton.

Nearfield studies were conducted to determine spatial patterns in zooplankton density. Alterations in the spatial distribution of zooplankton could result from losses caused by plant and/or plume entrainment. Analyses were directed toward demonstrating whether any reductions were evident at stations close to the plant site, and if so, whether they were indicative of plant-related depletion or were a reflection of more general reductions experienced over the study area. Studies 3 and 4 monitored stations in the nearfield, monthly, over an extended period. Study 4 was designed to assess impact by monitoring these same stations during both the preoperational and operational periods. Studies 5 and 6 were nearfield studies and included more replication of sampling than previous studies to allow for more rigorous statistical comparisons among stations and depths.

IV.4. - FINDINGS

IV.4.1. Entrainment Studies

- In most instances, zooplankton densities at the discharge station were lower than at the intake. Monthly analyses of samples taken at 4-hr intervals over a 24-hr period (Appendix C.1) indicated that average losses experienced through plant passage were about 30% in 1975, and reductions were greatest in August and September of 1975 and 1976. Analyses of the density reduction by species and age class indicated that copepod nauplii experienced the greatest losses. A similar trend, though not as pronounced, was also observed for Acartia tonsa copepodids, and to a lesser extent for A. tonsa adults and polychaete larvae (Appendices C.1 and C.2).
- Results of studies in which samples were taken every half-hour for one or two days indicated that densities recorded at the discharge fluctuated in parallel with densities recorded at the intake, but the differential between corresponding intake-discharge samples, a measure of the cropping rate, was not constant over time (Appendix C.2). In 1977, the cropping rate at night was 20 to 80% for Acartia tonsa, with copepodids and nauplii showing the greatest effects. During the day, the rate was substantially reduced to the 15 to 30% range. In 1978, entrainment losses increased with increasing overall density for organisms that demonstrated a cropping effect. Results of the 1979 studies were generally consistent with those obtained in 1977 and 1978; however,

overall densities in the 1979 entrainment studies were usually two to five times greater than those observed in the previous two years.

- Results of various live-dead studies (Appendices C.1 and C.2) were generally consistent and indicated low levels of observable mortality. The percentage of dye-specific (living) organisms were generally greater than 90% of the total sample at both the intake and discharge. Furthermore, there were no significant differences in the mortality rate between intake and discharge locations. These low levels of mortality suggest that density reductions noted in populations that experienced plant passage may not be due to thermal effects, but rather, they may result from other factors such as mechanical damage or may reflect nonrepresentative sampling.
- In May and June 1976 (Appendix C.1; Ref. 41) and in June and July 1978 (Appendix C.2; Ref. 1), abundances of barnacle larvae at the discharge site exceeded intake densities by as much as a factor of four. This was explained (Ref. 41) by suggesting that populations of fouling organisms, particularly of the barnacle species Balanus improvisus, growing on the walls of the discharge conduits were releasing nauplii during these periods. "The larvae of these barnacles appear to be released to the cooling water in such vast concentrations as to register a large increase in organisms collected in the cooling water discharged from the plant." (Ref. 41).
- Calculations indicated that, theoretically, the reproductive potential of adult barnacles living in the discharge conduits can account for observed increases in barnacle larvae (see above finding) at the discharge site (Appendix C.3).
- Sampling efficiencies of diaphragm pumps (low volume; used in most of the entrainment studies) and of Flygt pumps (high volume; used in a single experimental study) appeared to be similar in slow moving creek water and at the intake locations. Increasing the volume of the sample did not increase sampling efficiency (Appendix C.4). Although both pump types yielded density estimates at the discharge location that were reduced from comparable intake samples, the Flygt pump underestimated densities to a greater extent than did the diaphragm pump. Not yet known is the extent to which the lower discharge densities reported in most studies can be explained by reduced efficiency of diaphragm pumping.
- There was no observable increase in zooplankton "fragments" between samples taken at intake and discharge locations (Appendix C.4). This result suggests that density decreases between intake and discharge are not caused by mechanical destruction of animals, and it supports the idea that low discharge densities are a function of sampling method.
- The variability associated with sampling at different locations across the intake embayment was generally not significantly different from the variability among replicates at any one intake location. This result would indicate that one sampling location

across the intake embayment may be sufficient (Appendix C.4), and it suggests that intake densities reported in other entrainment studies at Calvert Cliffs are reasonably accurate estimates of true intake densities.

IV.4.2. Nearfield Studies

- The zooplankton community in the vicinity of Calvert Cliffs was typically estuarine, composed primarily of copepod crustaceans of all life stages. Other groups such as barnacle larvae, rotifers, tintinnids, polychaetes, and bivalve larvae, were often abundant and occasionally dominated samples. Acartia tonsa dominated the community in summer and early fall and were present year-round. A. clausi and Eurytemora affinis became abundant in winter and spring (Appendices C.5 through C.11).
- A series of statistical tests indicated that densities of Acartia tonsa nauplii were depleted in discharge-station (IIA) surface waters during the operational period (Appendix C.7). This depletion was evident even after accounting for longer-term trends that occurred over the entire study area. Surface densities of Acartia tonsa nauplii at the station closest to the discharge averaged 8% less than the average of densities at other inshore stations during the preoperational period. This density difference increased to 56% during the operational period, suggesting the possibility of a local plant effect. Similarly, densities at the discharge station were 34% less than average offshore densities during the preoperational period. This difference increased to 73% during the operational period. These values represent losses of 48% (inshore comparison) and 39% (offshore comparison) that may be considered attributable to plant operation (Appendix C.7). These density reductions are consistent with density reductions observed in entrainment studies. Although a density reduction for A. tonsa nauplii at other inshore stations (suggesting a plant effect) has been reported (Appendix C.10; Ref. 105), analyses conducted at station IA (Appendix C.7) did not demonstrate a plant-related effect.
- A density reduction of A. tonsa adults occurred at station IA during the operational period and appeared to indicate the possibility of a plant effect. However, the lack of a similar reduction for adults at the immediate discharge site, IIA, implies that station IA may also be unaffected.
- Acartia clausi, Eurytemora affinis, and tintinnid populations experienced a significant density reduction over the study area during the operational period. This reduction occurred over most stations, including those beyond the area of plant influence; thus, there was no evidence to indicate that these groups experienced a statistically significant power plant effect (Appendix C.7).
- Overall, zooplankton abundance tended to increase slightly with depth, suggesting that selective deep-water withdrawal for the

plant cooling system may increase entrainment of zooplankton (Appendix C.5). Copepod and barnacle nauplii did not demonstrate diel changes in depth preference, but they did tend to be higher in the water column during the spring-summer months.

- Results of other studies (Appendices C.6, C.8, and C.9) were considered preliminary, but generally, they supported results presented above.

IV.5. - SIGNIFICANCE OF FINDINGS

- Results of entrainment studies implied a considerable depletion of Acartia tonsa nauplii as a consequence of plant passage. The degree to which either thermal or mechanical damage or nonrepresentative sampling are responsible for these observed results has not yet been clearly demonstrated.
- Results of nearfield studies indicated a depletion of A. tonsa nauplii at the station closest to the discharge area during the period of plant operation. Since other stations were not similarly affected, the depletion and plant effect on A. tonsa nauplii must be considered localized. Except for a depletion of adult A. tonsa at station 1A during the operational period, the lack of a far-reaching impact on A. tonsa populations is further supported by a lack of a demonstrated plant-related effect on other A. tonsa life stages.
- Unlike results obtained for nauplii of the summer dominant A. tonsa, the plant did not cause significant population depletions for any life stage of the winter-spring copepods E. affinis and A. clausi, or for tintinnids.
- A low rate of zooplankton mortality would be expected from entrainment at Calvert Cliffs because of a combination of the following factors:
 - Brief entrainment time of four minutes
 - Moderate temperature rise of 5.5°C (recently increased to 6.7°C)
 - Jet type discharge causing rapid dispersal of plume
 - No uses of biocides in cooling system.

Table IV-1. Modes and possible consequences of interactions between zooplankton and a power plant.

Direct Interaction	Types of Stress	Possible Consequences to Organisms	Possible Consequences to Population
Plant entrainment	Thermal	Mortality	Reduced abundance of zooplankton in affected areas
	Mechanical	Physiological or morphological impairment. Results may include:	
		-- decreasing reproductive potential (stripping eggs from female copepods) -- increasing vulnerability to predation	
<hr/>			
Plume entrainment	Thermal	Mortality Physiological impairment	Reduced abundance of zooplankton in affected areas

Table IV-2. Descriptions of studies conducted at Calvert Cliffs relating to plant impact on zooplankton.

STUDY	RELEVANT SUMMARY APPENDICES	PARAMETERS MEASURED	SAMPLING METHOD	STATION LOCATIONS	SAMPLING FREQUENCY	PERIOD OF DATA COLLECTION	INFORMATION OBTAINED	REPORTS AND SOURCES (REF. NOS.)
1 Zooplankton entrainment (ANSP for BG&E)	C.1 C.2 C.3	Densities by species; condition (live-dead); barnacle reproduction	Pumped samples; vital stain, 48-hr time series	Intake and discharge	At least monthly, June to September	1975 - present	Entrainment effects on zooplankton	1,2,39-42, 103, 104, 114, 172
2 Zooplankton entrainment (UMC and MMC for PPSP)	C.4	Densities by species; condition (live-dead)	Pumped samples; vital stain	Intake and discharge	3 times in summer	1978-1979	Entrainment effects on zooplankton	113
3 Zooplankton survey (ANSP for BG&E)	C.5	Relative species abundance, biomass, diversity	Formerly 202- μ m mesh nets; currently pumped with 73- μ m-mesh concentrating nets	Plant site and reference stations	Monthly	1974 - present	Zooplankton population composition and distribution	99
4 Zooplankton survey (CBL and MMC for ERDA and PPSP)	C.6 C.7	Species, numbers, and concentration of organisms	Pumped samples at surface and near bottom	Plant site and reference stations	At least monthly	1971-1978	Species distribution	50,115-117,145
5 Zooplankton survey (CBL for PPSP)	C.8 C.9	Numbers of species; condition (live-dead)	Pumped samples; vital stain	Plant site and reference stations	Quarterly	1976	Zooplankton distribution	106,107, 109
6 Nearfield zooplankton study (CBL, MMC, and USNA for PPSP)	C.10 C.11	Zooplankton abundance and densities by species	Pumped samples	Plant site and reference stations	Quarterly	1977	Copepod densities at various depths and at near-plant-site and inshore stations	105,110-112

V. BENTHIC INVERTEBRATES

V.1. - INTRODUCTION

Bottom sediments and the surfaces of submerged objects such as shells provide habitats for many species of organisms collectively known as benthic invertebrates. Crabs, clams, and oysters are some of the larger and more familiar examples of the benthic fauna that are commercially harvested. Also important to the Chesapeake Bay ecosystem at Calvert Cliffs are the many smaller organisms (e.g., worms, snails, and small crustaceans) that are some of the primary food items of finfish, waterfowl, and blue crabs. As such they have significant roles in energy and material flows throughout the estuarine food web.

Over 100 benthic species have been collected from the Calvert Cliffs region. The abundant ones have a variety of sizes, tolerances to stress, modes of reproduction, methods of obtaining food, and other biological characteristics. The quantifiable characteristics of benthic communities (e.g., number of species, biomass or numerical density, and distribution of individuals among component species) are controlled by environmental conditions and may respond to any changes in conditions induced by plant operations. Thus, looking for differences in quantifiable community characteristics between reference and nearfield areas is theoretically both a sensitive means of determining the area of Bay bottom affected by plant operations and an integrative indicator of plant effects to higher and lower trophic levels.

Oysters, soft-shell clams, and blue crabs are the benthic species occurring at Calvert Cliffs that are commercially harvested and are among the most valuable of the Bay's resources. Their combined commercial landings have a dockside value in excess of 15 million dollars. The dollar value of the recreational fishery for these species has not been estimated, but for blue

crabs, it probably exceeds that of commercial landings. Recreational landings of oysters and soft-shell clams are not of significant dollar value.

V.2. - MODES OF BENTHIC ORGANISM-POWER PLANT INTERACTION AND THEIR SIGNIFICANCE

The manner in which benthic organisms interact with a power plant varies with life stage (Table V-1). Planktonic life stages (eggs and larval forms) may be entrained into the plant with cooling water flow or may be entrained into the thermal plume. Exposure to thermal and mechanical stresses during entrainment could cause direct mortality or physiological and morphological impairment. Because no biocide is used in the main cooling system at Calvert Cliffs, no major chemical stresses are experienced by organisms during entrainment.

Because natural mortality of the eggs and larvae of benthic organisms is generally very high, plant-induced losses of eggs and larvae would also have to be very large to significantly decrease the size of adult populations in the nearfield. Thus, entrainment is of greatest concern in cases where a power plant is located in a major spawning area of a species. Determination of the significance of entrainment losses requires a knowledge of what percentage of the spawn was lost. This percentage can then be used to project the loss of potential juveniles or adults. Impact assessment of entrainment losses to commercially important benthic species is based on the magnitude of losses of potential adults because the adult organisms are the exploited segment of the population. Impact assessment of entrainment losses to non-commercial benthic species is based on the magnitude of losses of potential juvenile organisms because the juveniles are the life stage having the dominant role in energy and material flows to higher trophic levels (i.e., they are generally the preferred food item of bottom feeding fish).

Another interaction benthic organisms can have with the plant is impingement on the screens. Only one benthic species, the blue crab, is impinged at Calvert Cliffs. Crabs larger than 1 cm may become trapped on the screens protecting intake structures for up to 1 hour before being washed into a trough and returned to the Bay. Crabs may die while trapped on the screens, or they may be injured by mechanical abrasion (e.g., loss of appendages) while they are on the screens or in the trough. Injury reduces their ability to compete when they are returned to the Bay. They may be more susceptible to predation or less able to obtain food. Because natural mortality of blue crabs is low once they reach 1 cm in size, impingement losses to juveniles and/or adults are direct measures of plant-induced mortalities. One way to determine the significance of these losses is to compare them with losses caused by other forms of exploitation such as commercial and/or recreational crab fishing.

A third interaction is exposure of organisms to the effects of plant discharge. Because most adult and juvenile benthic organisms have limited mobility, those in the discharge area may be continually exposed to thermal plume effects. Thermal increases experienced by benthic organisms in the plume at Calvert Cliffs are not large enough to cause any direct mortalities. However, the slightly higher than ambient temperatures in the plume area could have indirect or sublethal effects on physiological processes of benthic organisms. For example, the timing of reproduction or growth rate of a benthic organism in a thermally influenced region might be different from, or out of phase with, that of natural populations. This could reduce the ability of some species to compete and could eventually exclude some species from the plant site.

High velocity discharge currents in the plume region could alter sedimentation processes in the nearfield region. For example, fine sediment

particles in the immediate discharge region could be transported to and deposited on new sites. Since sedimentation processes and sediment characteristics are major environmental factors controlling the spatial distribution of benthic organisms, any changes in sediments due to plant operations would affect the spatial distribution of benthic populations.

An additional discharge effect that could influence benthic organisms is organic enrichment of bottom habitats when phytoplankton and zooplankton killed during entrainment are dispersed from the discharge conduit and settle to the bottom near the plant site. Some species of benthic organisms may be able to use this organic material as food (i.e., deposit feeding species), giving them a competitive advantage near the plant site. Nuisance organisms frequently become abundant in organically enriched habitats and could increase in abundance at the plant site at the expense of other preferable species. Organic enrichment could also make some near-plant habitats less favorable for some naturally occurring species, which could eventually be excluded from the plant site.

The condenser tubes of the Calvert Cliffs plant are made of a 70% copper-30% nickel alloy, which is corrosion-resistant but not inert. Copper released by estuarine power plants from corrosion of condenser tubes is adsorbed on particles suspended in the cooling water. These particles will ultimately settle to the bottom near the plant site, possibly enriching local sediments with copper. Some of the enriched particles could be ingested by benthic organisms and incorporated into their tissues. Copper enrichment may be stressful to certain benthic organisms, cause mortalities, or reduce reproductive potential. Because oysters are bioaccumulators of copper, they are especially susceptible to these potential effects.

Evaluation of discharge effects involves determination of the magnitude of losses or gains to benthic populations and determination of the effects changes have on food web relationships and ecosystem stability. For example, losses of preferred benthic food items in the discharge region could affect the growth rates or number of bottom feeding fish near the plant site.

Although these modes of interaction do not represent all possible means by which plant operations could affect benthic organisms, they are the major interactions between the plant and benthic organisms, which have been monitored at Calvert Cliffs.

V.3. - MONITORING STUDIES

Table V-2 briefly describes the studies at Calvert Cliffs dealing with benthic organisms.

Two studies of the total benthic community were conducted at Calvert Cliffs. Data collected by Study 1 from 1971-1975 can be used to characterize preoperational distribution patterns. The continuation of Study 1 after 1975 and Study 2 provide data to characterize conditions after plant operations began and to assess plant effects. Preoperational-operational comparisons and nearfield-reference area comparisons can both be used to test for plant effects.

Study 3 measured benthic respiration at the plant site and in reference areas only during the operational period. If plant operations were affecting the flow of energy and materials through the benthic community, both of which influence respiration, data obtained by this study would indicate the magnitude of the effect. Furthermore, data obtained by this study were necessary to determine how plant effects on lower trophic levels might influence the benthic community characteristics by changing the structure of the benthic food web.

Studies 4 and 5 examined the feeding habits of fish inhabiting the Calvert Cliffs area, collecting data necessary to determine whether plant effects on benthic organisms were passed on to higher trophic levels.

Study 6 was designed to characterize nearshore benthic communities before plant operations began and during plant operations to determine if plant-induced changes have occurred.

Several studies have been conducted to evaluate the effects of plant operations on oysters. Data collected by these studies can be used to determine: the effects of plant operations on oyster growth, meat condition, and mortality (Study 7); the effects of plant operations on oyster recruitment (Studies 8 and 9); the general abundance of oysters throughout the Calvert Cliffs region (Study 9); and whether copper and nickel released during plant operations are accumulating in oyster tissues (Studies 10 and 11).

Several studies were designed to evaluate plant effects on soft-shell clams. The abundance of soft-shell clams in the Calvert Cliffs region can be determined from data collected by Study 12. Studies 13 and 14 should be useful for determining the effects of plant operations on juvenile and planktonic stages of soft-shell clams. Data collected by Study 15 show whether plant operations affected the productivity of softshell clams in the Calvert Cliffs region.

Four studies were conducted to assess the effects of plant operations on blue crab populations. Study 16 investigated whether plant operations affected size, abundance, or sex ratio of blue crabs in the plant vicinity. Data collected by Study 17 can be used to evaluate the magnitude of blue crab impingement, and data collected by Study 18 can be used to determine whether impingement was a major source of crab mortalities. Study 19 was designed to determine natural distributional patterns of blue crabs in the

Calvert Cliffs region and to determine if plant operations affected these distributions.

V.4. - FINDINGS

V.4.1. Benthic Community

- Velocity fields from the high-velocity discharge system altered sediment characteristics and habitat type in the immediate discharge region by scouring sand from a 17-hectare zone. The scoured area was a marginal habitat for most burrowing benthic organisms. However, fouling organisms were an order of magnitude more abundant in the scoured area than they were in reference or preoperational-period shell habitats (Appendix section D.1.6).
- Plant operations did not have any detectable effects on benthic communities during summer and fall. During these seasons, predators were so overwhelmingly important in determining benthic community characteristics that the assessment of power plant effects was generally impossible.
- Plant operations resulted in increased abundance, growth rates, and productivity of some benthic species in the nearfield region during winter and spring. As a result, the structure of benthic communities in the nearfield area was frequently significantly different ($p < 0.05$) from that observed at reference areas or during the preoperational period during those seasons (D.1.6).
- No plant effects on the reproductive condition of benthic organisms were detected.
- No plant effects on the flow of energy and materials through benthic communities were observed (E.20.6 and D.3.6).
- Relatively large numbers of larval-stage clams (Macoma balthica and Macoma phenax) and planktonic-stage crustaceans and polychaetes are entrained (D.6.6). Survival of benthic organisms following entrainment is generally unknown.

V.4.2. Oysters

- The area near the plant does not have sufficient oyster densities to be a major commercial harvest area (D.7.5). No oyster larvae were collected from intake waters, indicating that reproductive success of oysters is extremely low in this area of the Bay (D.6.6). However, oysters that do settle in the vicinity of the plant apparently have high survival rates and typical growth patterns (D.7.6).

- Plant discharges increased the growth rate of oysters in the vicinity of the plant. No plant effects on the condition or mortality rates of tray-held oysters were observed (D.8.5).
- Copper concentrations in tissues of oysters near the discharge site have steadily increased since plant operations began (D.9.6 and D.10.6). In 1978, copper levels at the plant site were frequently high enough to give oysters a green color and bitter taste.
- Plant operations have not affected nickel levels in oyster tissues. Oysters apparently do not accumulate nickel in their tissues.

V.4.3. Soft-shell Clams

- The Calvert Cliffs region is not a major spawning area for soft-shell clams. Relatively few larval-stage soft clams were collected from the intake region (D.6.6).
- Commercially harvestable densities of soft-shell clams have not historically and do not now occur in the Calvert Cliffs region (D.4.6).
- Plant operations have increased the abundance, growth, and recruitment of soft-shell clams in the vicinity of the plant, resulting in production there being higher than in the reference areas (D.1.6); however, clam densities remain below harvestable levels.

V.4.4. Blue Crabs

- Plant operations have not affected blue crab populations in the Calvert Cliffs region (Appendix D.11). Large numbers of blue crabs are impinged (Appendix E.11), but mortalities from this stress are small (Appendix E.12).

V.5. - SIGNIFICANCE OF FINDINGS

- Entrainment losses of planktonic stages of most benthic organisms were not directly evaluated. However, the available data do not suggest that entrainment losses affect the abundance of juvenile or adult benthic organisms.
- The Calvert Cliffs region is not a major spawning area for any benthic species. Most of the benthic species in the Calvert Cliffs region live and reproduce in the entire mesohaline zone of the Chesapeake Bay. Even if a large percentage of the spawn that was entrained suffered mortality, it is likely that only local changes would result.

- There are no consistent decreases in adult populations near the plant site. Had such depletions occurred, they would probably have been detected.
- Recruitment success of many species of benthic organisms with entrainable life stages was greater at the plant site than it was at reference areas, making it unlikely that entrainment mortalities would affect adult abundances.
- Because natural mortalities of planktonic life stages of benthic organisms are high (95-99%), the incremental increase in mortality caused by entrainment is unlikely to alter the densities of adult or juvenile populations.
- Impingement of blue crabs does not have a significant impact on crab harvests in the Bay.
 - There was essentially no direct loss of blue crabs resulting from impingement mortality.
 - Blue crabs suffering sublethal effects from impingement are returned to the Bay where they will likely be eaten by natural predators (e.g., sea gulls, fish, or other crabs) or will die and decompose, releasing nutrients into the water. Thus, any impingement losses from sublethal impingement stresses modify the normal flows of energy and materials. However, it seems unlikely that sublethal effects of the magnitude caused by impingement are sufficient to modify the structure or functioning of the Bay ecosystem in the Calvert Cliffs region.
- The significant biological changes occurring in the scoured area will have little impact on the Bay ecosystem. Not only is the scoured area small, but there are as many or more benthic food organisms there as in adjacent habitats.
- The limited effects that plant operations had on benthic organisms outside of the scoured area will have no impact on the Bay ecosystem. Not only were the effects short-lived, but they also had no significant influence on food web relationships between benthic organisms and higher trophic levels (i.e., fish and crabs).
- Organic material from entrainment mortalities of phytoplankton and zooplankton was deposited near the plant site and may have effected some changes in benthic community characteristics. However, these effects were not pronounced and were not extended to the finfish community.
- Plant operations did not impact oyster or soft-shell clam yields of the Bay, and densities in the area are not high enough to support extensive commercial harvesting.

Table V-1. Modes and possible consequences of interactions between benthic invertebrates and a power plant.

Life Stage	Direct Interaction	Types of Stress	Possible Consequence to Organism	Possible Consequence to Population
Eggs and larvae	Entrainment (passage through cooling system)	Mechanical and physiological	Mortality; physiological or morphological impairment (e.g., greater vulnerability to predation), and redistribution (off-shore species may be redistributed into near-shore waters)	Increase or decrease in the number of eggs or larvae settling in the nearfield region (dependent on localization of spawning and number of larvae in intake waters), which could change densities of adult stocks near the plant site
	Plume entrainment (mixing with discharge waters)	Mechanical and physiological	Mortality; physiological or morphological impairment (e.g., mechanical damage occurs when larvae attempt to settle in regions that have high velocity currents); and redistribution (transport of eggs and larvae into offshore areas where survival may be higher or lower)	Increase or decrease the number of eggs or larvae settling in the nearfield region (dependent on localization of spawning and the number of larvae subjected to plume entrainment), which could change densities of adult stocks near the plant site
Juveniles and adults	Entrainment of small motile species	Mechanical and physiological	Mortality; abrasion (e.g., loss of appendages); physiological impairment (e.g., weakened organism not able to withstand natural stresses of estuarine environment; or distribution	Increase or decrease in local populations (dependent on population distributions), which could change the structure of benthic communities at the plant site

Table V-1. Continued.

Life Stage	Direct Interaction	Types of Stress	Possible Consequence to Organism	Possible Consequence to Population
Juveniles and adults (continued)	Impingement on intake screens	Mechanical and physiological	Mortality; abrasion (e.g., loss of appendages); or physiological impairment (e.g., weakened organism not able to withstand natural stresses of estuarine environment)	Increase or decrease in local populations (dependent on population distributions), which could change the structure of benthic communities at the plant site
	Exposure to elevated temperatures and high velocity currents in the plume	Mechanical and physiological	Mortality; abrasion; or change in physiological condition (e.g., change in the timing of reproduction) of organisms in the plume area	Increase or decrease in local stocks, which could change the structure of benthic communities near the plant site
	Exposure to organic enrichment resulting from plant-related entrainment mortalities	Change in sediment characteristics and type of food available	Change in the number, kinds, and growth rates of some species in the organically enriched area	Increase or decrease in local stocks, which could change the structure of benthic communities near the plant site
	Exposure to enriched levels of heavy metals from corrosion of condenser tubes	Physiological	Mortality from high levels of metal or change in physiological condition from low levels of metals	Change in the physiological condition and/or abundance of local stocks in the affected region. At high level of metal enrichment, commercially harvested species may become unfit for human consumption because of bad taste and green coloration
Juveniles and adults (continued)				

Table V-2. Descriptions of studies conducted at Calvert Cliffs relating to plant impact on benthic organisms.

STUDY	RELEVANT SUMMARY APPENDICES	PARAMETERS MEASURED	SAMPLING METHOD	STATION LOCATIONS	SAMPLING FREQUENCY	PERIOD OF DATA COLLECTION	INFORMATION OBTAINED	REPORTS AND SOURCES (REF. NOS.)
1 Benthic community and sediment study (MRC and CBL for PPSP and BGE)	D.1	Numbers and types of organisms, biomass; type and grain size of sediment	Anchor dredge and hydraulic grab	Plant site and reference stations	Quarterly	1971-1978	Benthic community profiles, prevailing sediment types, organism-sediment interactions	118-123
2 Benthic community survey (ANSP for BGE)	D.2	Sediment characteristics, and numbers and types of benthic macroinvertebrates	Smith-McIntyre grab samples sieved on 0.5-mm screens	Plant site and reference stations	Irregularly, March to December	1976 - 1979	Effects of thermal discharge on macroinvertebrate assemblages	148, 173
3 Benthic metabolism study (CBL for PPSP)	D.3	Oxygen consumption by benthic organisms	Monitor oxygen decrease under a dome located on bottom	Plant site and reference stations	Summer, fall, winter, spring	1977-1978	Plant effects on benthic metabolism	54, 65
4 Fish food preference study (CBL for PPSP)	E.19	Stomach contents of fish quantified	Stomachs of fish from 25-ft otter trawl samples were removed and examined	Plant site and reference stations	Day for 6 months, night for 3 of those	1977	Feeding habits of Calvert Cliffs fish community	126
5 Fish food habits study (ANSP for BGE)	E.20	Stomach contents of fish enumerated	Stomachs of fish from 25-ft otter trawl samples were removed and examined	Plant site and reference stations	Monthly	1971-1972	Composition of diet of bottom fish	25
6 Chesapeake Bay shallow-water surveys (ANSP for BGE)	F.1	Numbers by species of algae, protozoans, macroinvertebrates, and fish	Nets, scrapers, dredges, seines, and tongs	Plant site and reference stations	Twice per summer	1968-1974	Population profiles, preoperational Bay conditions	76-80
7 Oyster tray studies (ANSP for BGE)	D.8	Length, width, meat condition, viability; species and numbers of fouling organisms occurring with oysters	Random collections from oyster trays suspended in water	Plant site and reference stations	Quarterly	1970- present	Growth, fouling, and mortality	1,2,38-42,81-84, 164

Table V-2. Continued.

STUDY	RELEVANT SUMMARY APPENDICES	PARAMETERS MEASURED	SAMPLING METHOD	STATION LOCATIONS	SAMPLING FREQUENCY	PERIOD OF DATA COLLECTION	INFORMATION OBTAINED	REPORTS AND SOURCES (REF. NOS.)
8 Oyster spat survey (MMC and CBL for PPSP and DOE)	D.1	Numbers of juvenile oysters and quantity of shell	Oyster dredge	Calvert Cliffs area	March	1977	Density of oyster spat throughout Calvert Cliffs region	122
9 Oyster bar surveys (ANSP for BG&E)	D.7	Oyster density, growth, and condition	Dredge, tongs, underwater observations, and grab samples	Calvert Cliffs area	Irregularly	1967-1972, 1979	Abundance and condition of oysters, associated organisms	3, 28, 143, 170
10 Oyster heavy metal concentration (UDC for NASA)	D.10	Concentrations of heavy metals in oysters	Dredge samples	Calvert Cliffs area	Semi-annually	1974-1977	Heavy metal deposition	71
11 Oyster heavy metal concentration (ANSP for BG&E)	D.9	Concentrations of copper and nickel in oyster tissue	Oyster trays suspended in water	Plant site and reference stations	Quarterly	1973 - present	Oyster uptake of copper and nickel	1, 2, 38-42, 164
12 Adult soft-shell clam surveys (ANSP for BG&E)	D.4	Abundance of soft-shell clams (<i>Mya arenaria</i>)	Commercial dredge	Calvert Cliffs area	Annually	1972 - present	Status of soft-shell clam population	4-7, 171
13 Soft-shell clam entrainment (EAI for BG&E)	D.6	Soft-shell clam larval density	Larval table with 80-µm mesh netting	Intake	Weekly, during spawning season	1979	Amount of entrainment of soft-shell clams as a representative important species	139, 166
14 Juvenile soft-shell clam surveys (ANSP for BG&E)	D.5	Abundance of juvenile soft-shell clams	Bottle collectors	Plant site and reference stations	During spring and fall setting periods	1979	Spatial patterns of soft-shell clam settling in Calvert Cliffs area	144, 171
15 Production of soft-shell clams (MMC and CBL for PPSP and DOE)	D.1	Size, weight, and abundance of soft-shell clams	Anchor dredge and hydraulic grab sampler	21 stations throughout the Calvert Cliffs region	Quarterly	1971-1978	Soft-shell clam settling in the Calvert Cliffs area	123

Table V-2. Continued.

STUDY	RELEVANT SUMMARY APPENDICES	PARAMETERS MEASURED	SAMPLING METHOD	STATION LOCATIONS	SAMPLING FREQUENCY	PERIOD OF DATA COLLECTION	INFORMATION OBTAINED	REPORTS AND SOURCES (REF. NOS.)
16 Blue crab studies (ANSP for BG&E)	D.11	Size, weight, sex, and abundance	Commercial crab pots (5 per station, 3 in 1968)	Plant site and reference stations	Approximately biweekly, May to November	1968 - present	Relative abundance and condition of blue crab population	1,2,38-42,85-90, 164
17 Finfish and selected invertebrate impingement study (ANSP for BG&E)	E.11	Numbers by species; sizes	Samples collected from intake screen wash trough; crabs measured	Intake screens	1-hr collections, up to 6 days per week	1975 - present	Numbers and species of organisms impinged	1,2,39-42, 164
18 Impingement survival/mortality study (ANSP for BG&E)	E.12	Survival of impinged fish and crabs	Organisms from screen wash trough held in a pool; mortality was noted.	Intake screens	Weekly	1975-1976, 1978 - present	Impingement mortality, and survival rates	1,39,40
19 Bottom trawl blue crab surveys (CBL for PPSP)	E.15	Sex, weight, size, and relative abundance of blue crabs	Bottom trawls	Plant site and reference stations	Approximately monthly	1977-1978	Spatial distribution of blue crabs in the Calvert Cliffs area	66-69

VI. FINFISH

VI.1. - INTRODUCTION

Of the groups of Chesapeake Bay organisms exposed to power plant effects, finfish may be the one for which the public and various regulatory agencies show the most concern. This concern arises primarily from the great commercial and recreational value of a number of species. A second factor is that finfish recover slowly from population perturbations since they normally spawn once per year, unlike zooplankton that can regenerate every several days and phytoplankton that can double in numbers over a fraction of a day. Thus, losses in the finfish population due to plant-induced mortalities can only be recouped on an annual basis. For both these reasons, several intensive monitoring studies have been devoted to assessment of the impact of the Calvert Cliffs plant on finfish.

VI.2. - MODES OF FISH-POWER PLANT INTERACTION AND THEIR SIGNIFICANCE

Fish interactions with power plants vary depending on life stage (Table VI-1). Planktonic fish eggs and larvae may be entrained in the cooling water flow or in the thermal plume, where exposure to elevated temperatures and mechanical stresses could cause mortality or physiological and morphological impairment. Because natural mortality of fish eggs and larvae is very high, plant-induced losses of ichthyoplankton would normally have to be large to significantly modify the size of the adult fish population. Thus, entrainment causes the greatest concern related to any power plant located in the major spawning area of a species of interest. In such an area, eggs and larvae are concentrated and the potential for large entrainment losses is high. Assessment of the significance of ichthyoplankton losses requires

a knowledge of what percentage of the spawn was lost and an extrapolation of that loss to what the subsequent loss of adults would be. Impact assessment is based on the loss of potential adults, in part because the adult segment of the population is the exploited segment, but also because losses of individuals due to natural mortality are greatest prior to their reaching adulthood. Thus, the adult population essentially represents integration of the effects of both man-induced and natural mortality.

Adult and juvenile fish may be impinged on intake screens, which may either kill them directly or injure them by mechanical abrasion, making them more susceptible to predation or disease when they are returned to the Bay. Losses of juveniles must be extrapolated to losses of potential adults to assess the significance of plant effects at this life stage. Plant-induced losses of adults are measured directly, and the significance of the losses can be evaluated in a number of ways, including, for example, comparison with losses caused by different forms of commercial or recreational fishing.

Plume effects on juvenile and adult fish tend to be indirect at a plant like Calvert Cliffs where the heated discharge water is not confined to a semienclosed canal or embayment. Because of the relatively small increase in the temperature of cooling water as it passes through the plant (5.5°C), the high velocity discharge, and the rapid dispersion of heated water, most of the Calvert Cliffs plume has temperatures on the order of 1° to 2°C above ambient (see Chapter II), which are not lethal to Chesapeake Bay species. The plume shape and location will change markedly with tidal stage, so fish in a particular area are probably not constantly exposed to elevated temperatures. In addition, adult and juvenile fish are very mobile and can readily move in and out of areas with elevated temperatures. Thus, the primary environmental concern relative to the plume does not stem from direct mortality of fish,

but from the possibility that fish may avoid a portion of their normal habitat if temperatures are abnormal. Avoidance of normal spawning habitat may result in a population decline for many species. A second concern relative to the plume is that fish may aggregate in the heated waters in the fall or winter when ambient water temperatures are dropping or are low. Because most species of fish cannot adapt to rapid declines in temperature, such an aggregation would be susceptible to a cold-shock kill if the plant had to shut down, which would cause a sudden temperature drop in the discharge area.

In addition to these direct plant effects on finfish, there are also indirect effects passed through the food web. If plant operations alter the lower trophic levels that fish depend on for food, fish populations can be modified or reduced.

The modes of plant effect just discussed do not represent all possible means by which a power plant can influence fish populations. However, they do represent the major plant-fish interactions to which most monitoring studies at Calvert Cliffs have been directed.

VI.3. - MONITORING STUDIES

Table VI-2 briefly describes all studies dealing with finfish. (These studies are described in more detail in the E appendices.) Five ichthyoplankton studies have been carried out or are currently in progress (Studies 1-5). Studies 1 and 2 are essentially surveys. Data collected from 1971 to 1975 can be used to characterize fish spawning in the Calvert Cliffs area prior to plant operations. The continuation of those studies after 1975 provided data characterizing fish spawning in the plant area while the plant was operating. Study 3, carried out only when the plant was operating, employed more intensive sampling than studies 1 and 2. The objective of

Study 3 was to quantitatively compare ichthyoplankton densities near the plant to densities in unaffected areas. If plant operations were destroying ichthyoplankton, depletions near the plant site might be evidence of this destruction. Studies 4 and 5 were directed at quantifying the amounts of fish eggs and larvae entrained and the magnitude of mortality caused by entrainment.

Two types of impingement studies have been carried out since the plant began operating in 1975. Study 6 is designed to estimate the number of each species impinged during the year. Study 7 examines the extent of mortality caused by impingement for each species.

Studies 8, 9, and 10 have been carried out in the Calvert Cliffs area since 1968. The preoperational data from these surveys characterize the nearshore, midwater, and deepwater finfish communities in the undisturbed Bay ecosystem; the operational data can be used to characterize finfish abundance and community composition during plant operation to determine whether plant-induced changes have occurred.

The remaining studies were carried out only during plant operations. Study 11 employed a variety of sampling gears to ensure that all fish species were sampled and was designed to account for day-night and seasonal changes in fish distribution and abundance in assessing plant effects. Study 12 employed specialized sonar to search for plant-related changes in distribution and abundance of midwater fish species, which are not well sampled with the types of gear used in other studies. Studies 13 and 14 examined the feeding habits of fish inhabiting the Calvert Cliffs area. This information is necessary to evaluate the possibility that plant effects on lower trophic level organisms influence fish through the food web. Study 15 was carried out to assess the frequency and magnitude of natural fish kills in the vicinity of the power plant.

MMC has developed an estimation procedure for projecting impacts of power plant entrainment on fish populations (Refs. 175, 176). Maryland Water Quality Regulations (Section 08.05.04.13) require Baltimore Gas & Electric Company (BG&E) to demonstrate that plant cooling water and plume entrainment from the operation of the Calvert Cliffs Nuclear Power Plant do not affect a "spawning or nursery area of consequence for Representative Important Species (RIS)." Estimates of the potential impacts of the losses of early life stages of RIS caused by Calvert Cliffs entrainment are presented here to enable Maryland regulatory agencies to evaluate this aspect of the utility's demonstration.

The procedure used is essentially a linearized procedure that estimates relative impacts on population levels, regional economic yields, and affected-region trophic structures due to entrainment losses of egg, larval, and juvenile life stages of RIS at the Calvert Cliffs plant. Entrainment losses include estimates of mortality due to both passage through the cooling system and encounters with the discharge plume. Empirical field data from the studies just described are used in several mathematically simple conceptual submodels to estimate the "potential" loss of adults. The losses in each life stage are then evaluated ecologically in terms of the consequent productivity change in the lower Maryland Chesapeake Bay ecosystem. Projected losses to the adult population are assessed in economic terms as the potential change in value of the lower Maryland Chesapeake Bay fishery. The procedure assumes complete biological compensation for all phytoplankton and zooplankton entrainment losses, but not for finfish and shellfish population losses.

The results of these analyses are presented before in the Findings section of this chapter, so that the reader may contrast projected impact to the actual findings of field studies.

VI.4. - ESTIMATION OF POTENTIAL ENTRAINMENT IMPACT ON SPAWNING AND NURSERY AREAS NEAR CALVERT CLIFFS

VI.4.1. Introduction

The RIS of finfish examined in this assessment of entrainment impact are listed in Table VI-3. Only a summary of the methodology used is given here; a more complete description of the procedures can be found in Ref. 175.

VI.4.2. System Boundary Conditions and Physical Factors

The Calvert Cliffs Nuclear Power Plant facility is located on the western shore of the lower Maryland Chesapeake Bay in Calvert County, north of the mouth of the Patuxent River (Fig. VI-1). Because the water source used for cooling at the plant cannot be considered semi-enclosed, meaningful boundary conditions must be established to assess potential plant entrainment impact. These boundaries should be based on the migratory behavior, life history characteristics, and life-stage developmental times of each of the specific finfish species that can be entrained at the plant. The effective boundaries chosen for this analysis (to be discussed below) are indicated in Fig. VI-1, which shows the lower Maryland Bay region from the Calvert Cliffs plant (approximately Mile 87) to Mile 125. These boundaries were used for all entrainable larval and juvenile RIS populations. A smaller area (Mile 87-Mile 90) was chosen for the bay anchovy egg population based on hatching rate and water transport past the Bay cross section at the plant site.

Initial attempts to establish these boundary limits combined upper and lower water-layer discharges with cross-sectional areas measured at the plant and the developmental times of individual RIS life stages. Long-term, net,

water-layer-specific discharges in October 1977, as computed from Ref. 62, were 6,683 m³/s in the upper layer (0 to 12 m) and 3,640 m³/s in the lower layer (12 m to the bottom). Based on the cross-sectional areas of the upper and lower layers, 9.96×10^4 m² and 3.06×10^4 m², respectively (Ref. 177), the net velocities were estimated at 6.7 cm/s for the upper layer and 11.9 cm/s for the lower layer. For a mean developmental time of 35 days for early RIS life stages, the affected distances amounted to 308 km down-Bay from the plant for bottom-dwelling species, 174 km up-Bay for surface-dwelling species, and 154 km total (87 km up-Bay and 67 km down-Bay) for species migrating daily and spending 50% of their time in each water layer. Clearly, this estimate is too large to incorporate into the entrainment analysis. Moreover, it fails to consider attenuation of water velocity as the Bay widens in both the up-Bay and down-Bay directions and assumes that October flow is representative of the entire spawning and development period. Thus, the estimated distances for the boundaries of the potentially affected region are too high.

Consequently, we incorporated additional conditions in our calculations to obtain more limited -- but still realistic -- boundaries. For instance, the location of the Calvert Cliffs intake structure and the flow dynamics of the Bay in this region (Ref. 62) suggest that the bottom-layer, up-Bay-directed flow generally is not available for entrainment. Thus, only the upper layer (0-12 m) was considered in this analysis.

In addition, the October net discharge used above was not appropriate for our estimates because the "critical spawning and developmental period" for nearly all RIS in this region is April through October (except for the Atlantic croaker, which migrates into the region in December). Since the net estuarine circulation at the Calvert Cliffs cross section is driven primarily by Susquehanna River discharge (Ref. 62), the mean discharge during the critical period at

Calvert Cliffs was estimated from the mean 11-year Susquehanna flow -- $1,131 \text{ m}^3/\text{s}$ -- during the period of April-October for 1969-1979 (Table VI-4). Based on the relationship between the October 1977 Susquehanna River flow and the October 1977 net flow at Calvert Cliffs (Ref. 62), the mean Susquehanna discharge results in an estimated long-term, mean net discharge in both layers at Calvert Cliffs of approximately $1,312 \text{ m}^3/\text{s}$ from April to October. From the proportional relationship of upper- and lower-layer net flows at Calvert Cliffs described for October 1977 (Ref. 62), this mean net discharge past Calvert Cliffs from April to October results from an upper-layer discharge of $2,509 \text{ m}^3/\text{s}$ (velocity of 2.5 cm/s) and a lower-layer discharge of $1,197 \text{ m}^3/\text{s}$ (velocity 3.6 cm/s). Using the net velocity of the upper layer and a mean larval developmental time of 35 days, we derive an affected boundary distance of 77 km (approximately 37 nautical miles) up-Bay from the Calvert Cliffs facility. Thus, the upper boundary (for all cases except bay anchovy eggs) used in this analysis is Bay Mile 125 (Fig. VI-1). The vertical boundary of the zero net velocity is approximately at a 13-m depth near the Calvert Cliffs plant (Ref. 62). Plant operations generally interact only with the upper water layer, and the Calvert Cliffs cooling water withdrawal rate is relatively high. Because of these factors, the down-Bay extent of the affected region can be incorporated into the entrainment probability calculation simply by accounting for the oscillatory and advective movements of the water masses over a long period (i.e., 35 days). Thus, the probability of entrainment can be well approximated using only local densities of organisms and regional advective nontidal flow in the upper layer in the up-Bay direction.

VI.4.3. General Impact Evaluation Method

The computational logic and procedure for estimating the effects and potential impacts of entrainment from Calvert Cliffs operation are shown in

Fig. VI-2. Hierarchical levels of system change are shown by the vertical classifications. The four stages of computations -- community, population, physical, and economic -- represent the levels of effect on the lower Maryland Chesapeake Bay system.

Net deviation from long-term, steady-state population levels due to entrainment at Calvert Cliffs is calculated from the known preoperational RIS distributions in the lower Maryland Bay, life-stage behavior, and the probabilities of entrainment into the cooling system or plume. This projected population change (P_1) can be used to estimate the potential dollar losses (P_2) to the regional fishery of cooling system and plume entrainment and to compute the potential ecological change index (P_3) as unutilized net primary productivity in the system. Since only relatively small changes in all quantities are anticipated, all linearized computations are reasonable approximations. This assumption is especially reasonable for the Calvert Cliffs region of the lower Maryland Bay because RIS populations in this area are widely distributed, and plant design and tidal flow are complex enough to integrate potential local population depletions. However, even if changes are in the acceptable range for linearization, population losses may result in nontrivial economic and/or ecological effects.

Since the biological and economic measures shown here are relative indicators of impact resulting from cooling-system and plume entrainment at the Calvert Cliffs facility, the importance of these impacts must be evaluated based on local experience. Ramifications of the general methodology are discussed more completely in Ref. 175.

VI.4.4. Probabilities of Entrainment

The probability of planktonic or semi-planktonic life stages of RIS encountering either the Calvert Cliffs cooling system or the effluent plume depends on the rate of water withdrawal by the plant and the volume of estuarine water transported by the plant that is available for cooling. By comparing the water withdrawal rate to the total mean discharge through the cross section of the Bay across from the plant, modified by the plant recirculation rate, we can determine the probability that a parcel of water passing the facility will be drawn into the cooling system. As stated previously, total mean discharge for the critical spawning period for RIS was estimated as 3,706 m³/s, based on mean Susquehanna discharge from April-October. (Mean upper- and lower-layer discharges were estimated to be 2,509 m³/s and 1,197 m³/s from data in Ref. 62.)

The probability of condenser entrainment of new water is then approximated as:

$$P_E = 1 - \exp \left[- \left(\frac{Q_P}{Q_T} \right) (1 - P_R) \right]$$

where

P_E = probability of condenser entrainment,
 Q_T = total water transport available for entrainment (equals upper layer discharge, Q_U , in this case),
 Q_P = cooling system circulation rate, and
 P_R = probability of cooling water recirculation.

These quantities are shown in Table VI-5. The probability of "new" water passing through the Bay cross section at the site and being entrained into the cooling system (P_E) is 0.055, or 5.5% of net upper layer transport.

Plume entrainment probability is much more difficult to estimate. A comparison of the cross-sectional areas of the 2°C excess temperature plume and the receiving body was arbitrarily chosen as a reasonable approximation; thus, the probability of encounter with the plume (P_P) could be estimated as:

$$P_p = A_C/A_T$$

where

A_C = mean 24-hour cross-sectional area of the 2°C excess temperature isotherm, and

A_T = total estuarine cross-sectional area where A_C is available to mix with discharge (equals A_U in this case).

The mean 24-hour cross-sectional area of the excess 2°C isotherm is 2,415 m² (Refs. 43-46); the available receiving cross-sectional area is 9.96 x 10⁴ m² (Ref. 177). Thus, the probability of "new" water encountering the Calvert Cliffs plume is 0.024, or 2.4% of the net upper-layer transport.

VI.4.5. RIS Population Losses

The computational scheme for the estimation of relative population losses for RIS due to entrainment at Calvert Cliffs is given in Fig. VI-3. At a gross level, population losses are the integrated products over time of entrainment mortality probabilities and life-stage densities normalized to the size of the entire life-stage population in the region. The procedure also accounts for the number of generations occurring at each life stage during the entire spawning and development period, and the diel migratory behavior of the life stage. The proportion (P_{ij}) of the regional life-stage population j of species i potentially lost due to cooling system entrainment at Calvert Cliffs is:

$$P_{ij} = P_E \cdot Q_k \cdot L_{ij} \cdot \frac{T_{ijk} \cdot D_{ij}^* \cdot M_{ijE}}{\bar{D}_{ij} \cdot V_{ij} \cdot N_{ij}}$$

where

Q_k = discharge rate in water layer k where cooling water is withdrawn,

L_{ij} = length of time that life stage j of species i occurs in exposed water column,

T_{ijk} = proportion of diurnal time-span that life stage j of species i spends in water layer k ,

\bar{D}_{ij} = mean regional density of life stage j or species i over L_{ij} ,

D_{ij}^* = mean local density of life stage j of species i over L_{ij} ,

V_{ij} = volume of region inhabited by life stage j of species i that is potentially vulnerable to entrainment,
 M_{ijE} = mortality rate due to cooling system entrainment of life stage j of species i (assumed to be 100% for all stages),
 N_{ij} = number of generations of life stage j of species i during period of susceptibility.

The proportional loss for each life stage j of species i to the regional population due to plume entrainment (W_{ij}) can be expressed as:

$$W_{ij} = P_p \cdot Q_d \cdot L_{ij} \cdot \frac{T_{ijd} \cdot D_{ij}^* \cdot M_{ijp}}{\bar{D}_{ij} \cdot V_{ij} \cdot N_{ij}}$$

where

Q_d = transport rate in water layer d in which the plant discharge plume is located,
 T_{ijd} = proportion of diurnal time-span that life stage j of species i spends in water layer d , and
 M_{ijp} = mortality rate due to plume entrainment of life stage j of species i (assumed to be 10% for egg and larval stages and 1% for juveniles).

Both types of entrainment losses can be compared for all life stages (ℓ) to estimate an equivalent adult population loss (P_1) as:

$$P_1 = 1 - \prod_{j=1}^{\ell} [1 - (P_{ij} + W_{ij})].$$

Local and regional RIS life-stage densities are given in Table VI-6. These mean densities for April to October were determined from preoperational studies conducted from 1969-1974 (Refs. 32-36, 50, 59, 115-117). Only pre-operational data were used to preclude any effect on densities by plant operations. For each RIS life-stage, Table VI-7 gives the developmental times, the location in the water column, and the lengths of time spent in the lower Maryland Chesapeake Bay. A more complete documentation of the life history characteristics of RIS is given in Ref. 175.

Table VI-8 shows the potential entrainment losses calculated from these parameters, diel migratory behavior, estimates of RIS life-stage standing stocks, layer-specific water transports, and the probabilities of cooling-system and plume entrainment. These calculations suggest that Atlantic croaker, bay anchovy, and possibly naked goby and winter flounder populations may be affected by the operation of the Calvert Cliffs facility. The effects would be seen primarily in the larval stages of each population. Within the previously defined "affected" area, the magnitude of the estimated population changes due to entrainment losses is small, with the exception of equivalent adult losses in Atlantic croaker (6.4%) and bay anchovy (5.0%). However, the impact, or significance, associated with these changes must be interpreted based on the economic changes they would produce in the lower Maryland Chesapeake Bay fishery, and on the ecological changes in the ecosystem energy flow of this region.

The above results are conditioned by our assuming 100% mortality for all organisms entrained into the Calvert Cliffs cooling system and 1-10% mortality, depending on life stage, for plume entrainment. Recent studies (e.g., Ref. 166) suggest that cooling system entrainment mortalities at Calvert Cliffs may be significantly less than 100%. While no mortality rate estimates were determined for bay anchovy larvae (due to inadequate catch), mortality rates were estimated for Atlantic menhaden juveniles (76%), spot juveniles (18%), and naked goby larvae (44%). Consequently, all the population loss estimates would be lower than the computed values if more realistic estimates of cooling system mortality rates at Calvert Cliffs were used in the calculations. Little data exist on the actual mortality rates associated with plume entrainment. Again, all population loss estimates probably would decrease if actual mortality estimates were known.

VI.4.6. Impact of Population Economic Losses

The potential economic losses associated with the potential population losses due to entrainment at Calvert Cliffs were estimated from historical and present dollar values of the individual fisheries of the lower Maryland Chesapeake Bay. The computational method for determining the economic effects of entrainment losses is shown in Fig. VI-4. The key variables are the long-term, mean economic value of the lower Maryland Chesapeake Bay fishery, the values of individual exploited species, and the losses of equivalent adults of RIS populations.

The proportional value loss (P_2) to the lower Maryland Chesapeake Bay fishery due to population losses of species i through entrainment is:

$$P_2 = P_1 \quad V_i / \sum_i V_i$$

where

- P_1 = computed equivalent adult population losses of species i ,
- V_i = mean annual dollar value of species i in the lower Maryland Chesapeake Bay fishery, and
- $\sum_i V_i$ = total mean dollar value of lower Maryland Chesapeake Bay fishery.

The economic effect of all species losses due to entrainment may then be expressed as:

$$E_2 = \sum_i P_{2i}.$$

To estimate the dollar value of population losses due to Calvert Cliffs entrainment, we must know the value structure of the lower Maryland Chesapeake Bay fishery. This economic information (Table VI-9) was provided by the Tidewater Fisheries Division of the Maryland Tidewater Administration (Ref. 179) and derived from calculations based on sportfishing surveys in Chesapeake Bay (Ref.